CHAPTER 15

FOUNDATIONS ON FILL AND BACKFILLING

15-1. Types of fill.

a. Fills include conventional compacted fills; hydraulic fills; and uncontrolled fills of soils or industrial and domestic wastes, such as ashes, slag, chemical wastes, building rubble, and refuse. Properly placed compacted fill will be more rigid and uniform and have greater strength than most natural soils. Hydraulic fills may be compacted or uncompacted and are an economical means of providing fill over large areas. Except when cohesionless materials, i.e., clean sands and gravels, are placed under controlled conditions so silty pockets are avoided and are compacted as they are placed, hydraulic fills will generally require some type of stabilization to ensure adequate foundations.

b. Uncontrolled fills are likely to provide a variable bearing capacity and result in a nonuniform settlement. They may contain injurious chemicals and, in some instances, may be chemically active and generate gases that must be conducted away from the structure. Foundations on fills of the second and third groups (and the first group if not adequately compacted) should be subjected to detailed investigations to determine their suitability for supporting a structure, or else they should be avoided. Unsuitable fills often can be adequately stabilized.

15-2. Foundations on compacted fills.

a. Compacted fill beneath foundations. Compacted fills are used beneath foundations where it is necessary to raise the grade of the structure above existing ground or to replace unsatisfactory surface soils. Fills constructed above the natural ground surface increase the load on underlying soils, causing larger settlements unless construction of the structure is postponed until fill-induced settlements have taken place. Settlements beneath a proposed fill can be computed using methods outlined in chapter 5. If computed settlements are excessive, consider surcharging and postponing construction until the expected settlement under the permanent fill loading has occurred. Extend the fill well beyond the loading area, except where the fill is placed against a cut slope. Where the fill is relatively thick and is underlain by soft materials, check its stability with respect to deep sliding. If the fill is underlain by weaker materials, found the footings on the fill unless settlement is excessive. If the fill is underlain by a stronger material, the footings may be founded on the fill or on the stronger material.

b. Foundations partially on fill. Where a Sloping ground surface or variable foundation depths would result in supporting a foundation partially on natural soil, or rock, and partially on compacted fill, settlement analyses are required to estimate differential settlements. In general, a vertical joint in the structure should be provided, with suitable architectural treatment, at the juncture between the different segments of foundations. The subgrade beneath the portions of foundations to be supported on natural soils or rock should be undercut about 3 feet and replaced by compacted fill that is placed at the same time as the fill for the portions to be supported on thicker compacted fill.

c. Location of borrow. Exploratory investigations should be made to determine the suitable sources of borrow material. Laboratory tests to determine the suitability of available materials include natural water contents, compaction characteristics, grain-size distribution, Atterberg limits, shear strength, and consolidation. Typical properties of compacted materials for use in preliminary analyses are given in table 3-1. The susceptibility to frost action also should be considered in analyzing the potential behavior of fill material. The scope of laboratory testing on compacted samples depends on the size and cost of the structure, thickness and extent of the fill, and also strength and compressibility of underlying soils. Coarse-grained soils are preferred for fill; however, most fine-grained soils can be used advantageously if attention is given to drainage, compaction requirements, compaction moisture, and density control.

d. Design of foundations on fill. Foundations can be designed on the basis of bearing capacity and settlement calculations described in chapter 10. The settlement and bearing capacity of underlying foundation soils also should be evaluated. Practically all types of construction can be founded on compacted fills, provided the structure is designed to tolerate anticipated settlements and the fill is properly placed and compacted. Good and continuous field inspection is essential.

e. Site preparation. The site should be prepared by clearing and grubbing all grass, trees, shrubs, etc. Save as many trees as possible for environmental considerations. The topsoil should be stripped and stockpiled for later landscaping of fill and borrow areas. Placing and compacting fills should preferably be done when the area is still unobstructed by footings or other construction. The adequacy of compacted fills for supporting structures is dependent chiefly on the uniformity of the compaction effort. Compaction equipment generally can be used economically and efficiently only on large areas. Adverse weather conditions may have a pronounced effect on the cost of compacted fills that are sensitive to placement moisture content, i.e., on materials having more than 10 to 20 percent finer than the No. 200 sieve, depending on gradation.

f. Site problems. Small building areas or congested areas where many small buildings or utility lines surround the site present difficulties in regard to maneuvering large compaction equipment. Backfilling adjacent to structures also presents difficulties, and power hand-tamping equipment must be employed, with considerable care necessary to secure uniform compaction. Procedures for backfilling around structures are discussed in TM 5-818-4 / AFM 88-5, Chapter 5.

15-3. Compaction requirements.

a. General. Guidelines for selecting compaction equipment and for establishing compaction requirements for various soil types are given in table 15-1. If fill materials have been thoroughly investigated and there is ample local experience in compacting them, it is preferable to specify details of compaction procedures, such as placement water content, lift thickness, type of equipment, and number of passes. When the source of the fill or the type of compaction equipment is not known beforehand, specifications should be based on the desired compaction result, with a specified minimum number of coverages of suitable equipment to assure uniformity of compacted densities.

b. Compaction specifications. For most projects the placement water content of soils sensitive to compaction moisture should be within the range of -1 to + 2 percent of optimum water content for the field compaction effort applied. Each layer is compacted to not less than the percentage of maximum density specified in table 15-2. It is generally important to specify a high degree of compaction in fills under structures to minimize settlement and to ensure stability of a structure. In addition to criteria set forth in TM 5-818-4/AFM 88-5, Chapter 5, the following factors should be considered in establishing specific requirements:

(1) The sensitivity of the structure to total and differential settlement as related to structural design is particularly characteristic of structures to be founded partly on fill and partly on natural ground.

(2) If the ability of normal compaction equipment to produce desired densities in existing or locally available materials within a reasonable range of placement water content is considered essential, special equipment should be specified.

(3) The compaction requirements for clean, cohesionless, granular materials will be generally higher than those for cohesive materials, because cohesionless materials readily consolidate, or liquify, when subjected to vibration. For structures with unusual stability requirements and settlement limitations, the minimum density requirements indicated in table 15-2 should be increased. For coarse-grained, well-graded, cohesionless soils with less than 4 percent passing the No. 200 sieve, or for poorly graded cohesionless soils with less than 10 percent, the material should be compacted at the highest practical water content, preferably saturated. Compaction by vibratory rollers generally is the most effective procedure. Experience indicates that pervious materials can be compacted to an average relative density of 85 $\pm$ 5 percent with no practical difficulty. For cohesionless materials, stipulate that the fill be compacted to either a minimum density of 85 percent relative density or 95 percent of CE 55 compaction effort, whichever gives the greater density.

(4) If it is necessary to use fill material having a tendency to swell, the material should be compacted at water contents somewhat higher than optimum and to no greater density than required for stability under proposed loadings (table 15-2). The bearing capacity and settlement characteristics of the fill under these conditions should be checked by laboratory tests and analysis. Swelling clays can, in some instances, be permanently transformed into soils of lower plasticity and swelling potential by adding a small percentage of hydrated lime (chap 16).

c. Compacted rock. Compacted crushed rock provides an excellent foundation fill. Vibratory rollers are preferable for compacting rock. Settlement of fill under the action of the roller provides the most useful information for determining the proper loose lift thickness, number of passes, roller type, and material gradation. Compaction with a 10-ton vibratory roller is generally preferable. The rock should be kept watered at all times during compaction to obviate collapse settlement on loading and first wetting. As general criteria for construction and control testing of rock fill are not available, test fills should be employed where previous experience is inadequate and for large important rock fills.

15-4. Placing and control of backfill. Backfill should be placed in lifts no greater than shown in table 15-1, preferably 8 inches or less and dependingon the soil and type of equipment available. No backfill should be placed that contains frozen lumps of soil, as later thawing will produce local soft spots. Backfill should not be placed on muddy, frozen, or frost-cov-

Table 15-1. A summary of Density Methods for Building Foundation

Soil Group	Soil Types	Degree of Compaction		Fill and Backfill: Typical Equipment and Procedures for Compaction: Equipment	No. of Passes or Coverages	Comp. Lift Thick., in.	Placement Water Content	Fill and Backfill: Field Control	Deep Foundation Deposits: Compaction Methods	Deep Foundation Deposits: Field Control
Pervious (Free-Draining)	GW GP SW SP	Compacted	90 to 95% of CE 55 maximum density 75 to 85% of relative density	Vibratory rollers and compactors	Indefinite	Indefinite	Saturate by flooding	Control samples at intervals to determine degree of compaction or relative density	None available except for near surface (to approximate depth of 5 ft) compaction by equipment and procedure shown at left	
				Rubber-tired roller[a]	2-5 coverages	12				
				Crawler-type tractor[b]	2-5 coverages	8				
				Power hand tamper[c]	Indefinite	6				
		Semicompacted	85 to 90% of CE 55 maximum density 65 to 75% of relative density	Rubber-tired roller[a]	2-5 coverages	14	Saturate by flooding	Control samples as noted above, if needed	Vibroflotation, compaction piles, sand piles, explosives Surface compaction as noted above	Undisturbed samples from borings or test pits to determine degree of compaction or relative density
				Crawler-type tractor[b]	1-2 coverages	10				
				Power hand tamper[c]	Indefinite	8				
				Controlled routing of construction equipment	Indefinite	8-10				
Semipervious and Impervious	GM GC SM SC ML CL OL OH MH CH OH	Compacted	90 to 95% of CE 55 maximum density	Rubber-tired roller[a]	2-5 coverages	8	Optimum water content based on CE 55 test with 12 blows per layer	Control samples at intervals to determine degree of compaction	(A) Surface compaction by equipment and procedures shown at left is feasible only if material is at proper water content (B) Densification of soils is controlled by consolidation process (a) preload fills* (b) lowering of ground-water table (c) drying * Consolidation may be accelerated by means of sand drains Field control exercised by observation of pore pressures and surface settlements	
				Sheepsfoot roller[d]	4-8 passes	6				
				Power hand tamper[c]	Indefinite	4				
		Semicompacted	85 to 90% of CE 55 maximum density	Rubber-tired roller[a]	2-4 coverages	10	(A) Optimum water content based on CE 55 test with 7 blows per layer (B) By observation; wet side-maximum water content at which material can satisfactorily operate, dry side-minimum water content required to bond particles and which will not result in voids or honeycombed material	(A) Control samples as noted above, if needed (B) Field control exercised by visual inspection of action of compacting equipment		
				Sheepsfoot roller[d]	4-8 passes	8				
				Crawler-type tractor[b]	3 coverages	6				
				Power hand tamper[d]	Indefinite	6				
				Controlled routing of construction equipment	Indefinite	6-8				

Note: The above requirements will be adequate in relation to most construction. In special cases where tolerable settlements are unusually small, it may be necessary to employ additional compaction equivalent to 95 to 100% of CE 55 compaction effort. A coverage consists of one application of the wheel of a rubber-tired roller or the threads of a crawler-type tractor over each point in the area being compacted. For a sheepsfoot roller, one pass consists of one movement of a sheepsfoot roller drum over the area being compacted.

(a) Rubber-tired rollers having a wheel load between 18,000 and 25,000 lb and a tire pressure between 80 and 100 psi.
(b) Crawler-type tractors weighing not less than 20,000 lb and exerting a foot pressure not less than 6-1/2 psi.
(c) Power hand tampers weighing more than 100 lb; pneumatic or operated by gasoline engine.
(d) Sheepsfoot rollers having a foot pressure between 250 and 500 psi and tamping feet 7 to 10 in. in length with a face area between 7 and 16 sq in.

Table 15-2. Compaction Density as a Percent of CE 55 Labortory Test Density

	CE 55 Maximum Density, %	
	Cohesive Soils	Cohesionless Soils
Fill, embankment, and backfill		
Under proposed structures, building slabs, steps, and paved areas	90	95[a]
Under sidewalks and grassed areas	85	90
Subgrade		
Under building slabs, steps, and paved areas, top 12 in.	90	95
Under sidewalks, top 6 in.	85	90

[a] May be 85% relative density, whichever is higher.

ered ground. Methods of compaction controf during construction are described in TM 5-818-4/AFM 88-5, Chapter 5.

15-5. Fill settlements. A fill thickness of even 3 feet is a considerable soil load, which will increase stresses to a substantial depth (approximately 2B, where B = smallest lateral dimension of the fill). Stress increases from the fill may be larger than those from structure footings placed on the fill. Use procedures outlined in chapter 10 to obtain expected settlements caused by fill loading. Many fills are of variable thickness, especially where an area is landscaped via both cutting and filling to obtain a construction site. In similar cases, attention should be given to building locations with respect to crossing cut and fill lines so that the proper type of-building settlement can be designed (building may act as a cantilever, or one end tends to break off, or as a beam where the interior sags). Proper placing of reinforcing steel in the wall footings (top for cantilever action or bottom for simple beam action) may help control building cracks where settlement is inevitable; building joints can be provided at critical locations if necessary. The combined effect of structure (one- and two-story residences) and fill loading for fills up to 10 feet in thickness on sound soil and using compaction control should not produce a differential settlement of either a smooth curved hump or sag of 1 inch in 50 feet or a uniform slope of 2 inches in 50 feet.

15-6. Hydraulic fills. Hydraulic fills are placed on land or underwater by pumping material through a pipeline from a dredge or by bottom dumping from barges. Dredge materials vary from sands to silts and fine-grained silty clays and clays. Extensive maintenance dredging in the United States has resulted in disposal areas for dredge materials, which are especially attractive from an economic standpoint for development purposes. Dikes are usually required to retain hydraulic fills on land and may be feasible for underwater fills. Underwater dikes may be constructed of large stones and gravel.

a. Pervious fills. Hydraulically placed pervious fills with less than 10 percent fines will generally be at a relative density of 50 to 60 percent but locally may be lower. Controlled placement is necessary to avoid silt concentrations. Compaction can be used to produce relative densities sufficient for foundation support (table 15-1). Existing uncompacted hydraulic fills of pervious materials in seismic areas are subject to liquefaction, and densification will be required if important structures are to be founded on such deposits. Rough estimates of relative density may be obtained using standard penetration resistance. Undisturbed borings will be required to obtain more precise evaluation of in situ density and to obtain undisturbed samples for cyclic triaxial testing, if required. For new fills, the coarsest materials economically available should be used. Unless special provisions are made for removal of fines, borrow containing more than 10 percent fines passing the No. 200 sieve should be avoided, and even then controlled placement is necessary to avoid local silt concentrations.

b. Fine-grained.fills. Hydraulically placed overconsolidated clays excavated by suction dredges produce a fill of clay balls if fines in the washwater are permitted to run off. The slope of such fills will be extremely flat ranging from about 12 to 16H on 1V.

(1) These fills will undergo large immediate con-

solidation for about the first 6 months until the clay balls distort to close void spaces. Additional settlements for a 1-year period after this time will total about 3 to 5 percent of the fill height.

(2) Maintenance dredgings and hydraulically placed normally consolidated clays will initially be at water contents between 4 and 5 times the liquid limit. Depending on measures taken to induce surface drainage, it will take approximately 2 years before a crust is formed sufficient to support light equipment and the water content of the underlying materials approaches the liquid limit. Placing 1 to 3 feet of additional conhesionless borrow can be used to improve these areas rapidly so that they can support surcharge fills, with or without vertical sand drains to accelerate consolidation. After consolidation, substantial one- or two-story buildings and spread foundations can be used without objectionable settlement. Considerable care must be used in applying the surcharge so that the shear strength of the soil is not exceeded (i.e., use light equipment).

c. Settlements of hydraulic fills. If the coefficient of permeability of a hydraulic fill is less than 0.0002 foot per minute, the consolidation time for the fill will be long and prediction of the behavior of the completed fill will be difficult. For coarse-grained materials with a larger coefficient of permeability, fill consolidation and strength buildup will be relatively rapid and reasonable strength estimates can be made. Where fill and foundation soils are fine-grained with a low coefficient of permeability, piezometers should be placed both in the fill and in the underlying soil to monitor pore pressure dissipation. It may also be necessary to place settlement plates to monitor the settlement. Depending on the thickness of the fill, settlement plates may be placed both on the underlying soil and within the fill to observe settlement rates and amounts.

d. Compaction of hydraulic fills. Dike-land hydraulic fills can be compacted as they are placed by use of-

(1) Driving track-type tractors back and forth across the saturated fill. (Relative densities of 70 to 80 percent can be obtained in this manner for cohesionless materials.)

(2) Other methods such as vibratory rollers, vibroflotation, terraprobing, and compaction piles (chap 16). Below water, hydraulic fills can be compacted by use of terraprobing, compaction piles, and blasting.

e. Underwater hydraulic fills. For structural fill placed on a dredged bottom, remove the fines dispersed in dredging by a final sweeping operation, preferably with suction dredges, before placing the fill. To prevent extremely flat slopes at the edge of a fill, avoid excessive turbulence during dumping of the fill material by placing with clamshell or by shoving off the sides of deck barges. To obtain relatively steep slopes in underwater fill, use mixed sand and gravel. With borrow containing about equal amounts of sand and gravel, underwater slopes as steep as 1V on 2H may be achieved by careful placement. Uncontrolled bottom dumping from barges through great depths of water will spread the fill over a wide area. To confine such fill, provide berms or dikes of the coarsest available material or stone on the fill perimeter.